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Environmental Implications of Management Interventions in the Pig Fattening Process

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Summary

To achieve a precise description of substance flows and of the output of pollutants in animal husbandry the specific design of the production process has to be considered. However, the only factor influencing the process is the economy. Techniques for emission reduction are generally an addition and are not incorporated during the process or when making management decisions. At the Institute of Agricultural Engineering Potsdam a decision support system was developed to assess the environmental damages caused by aerial pollutants during the pig production process and the efficiency of various emission reduction measures. Varying the intensity of the process the system shows potential for the retention of substances in the process which is comparable to direct emission reduction means such as biofilters, acidification of manure or different ways of covering the manure. A cost calculation gives evidence about the changes in costs and the margin which is available for environmental protection.

The program also calculates environmental damage costs. Given the default values for pollutants they vary between 4 - 9 % of the total production cost.

Introduction

The goal of the project was to set up an inventory of aerial pollutants of the pig fattening process and to assess different emission reduction means. The inventory should give realistic estimates of released emissions for a defined production process. These emission data should be able to be compared to production cost and damage cost for the released substances.

Methods - *Description of* SIMSET

The software system used describes the substance flows and costs of the fattening process related to the production process. The variables of the production process come from the following areas:

- production level (quantity, starting weight, final weight, average weight gain)
- breed
- husbandry system

- fodder quantity and quality and the fodder regime
- manure management system
- emission reduction means

Breed-specific growth curves of pigs were derived from productivity tests of the Hessische Landesanstalt für Tierzucht (HLT) Neu Ulrichstein, Germany. The considered breeds were: Deutsche Landrasse (DL), Deutsches Edelschwein (DE), Pietrain and the crossbreeds DL x DE, Duroc x DL or Pietrain x DL. The appropriate curves are adapted to the specified production level expressed as average daily weight gain in grams by iteration.

The chosen growth curve is the basis for calculation of the substance flows. Carbon, nitrogen and phosphorus substance flows are calculated using two methods:

- a hypothetical calculation about the minimum requirements of the animal under given general production data
- the actual (entered) consumption of feedstuffs and the resulting actual substance flow

The minimum calculations are based on equations of KIRCHGESSNER (1992), MEYER et al. (1993) and SUSENBETH (1993) which describe the conversion of fodder energy and protein to body mass. The carcass composition at the final fattening stage is also derived from an equation of KIRCHGESSNER (1992). For the emission calculations and the calculation of the remainder the actual consumption data are used.

The substance flows are calculated as the excretion of phosphorus, carbon and nitrogen. The difference between the actual and hypothetical minimum substance flows characterises the efficiency of the process. The second block of the menu, shown in the figure below, is dedicated to the expected emissions of CO_2, CH_4, NH_3 and N_2O and the last column shows the remainder which is the possible input for plant production. The figure below shows the first output menu of SIMSET concerning the substance flows.

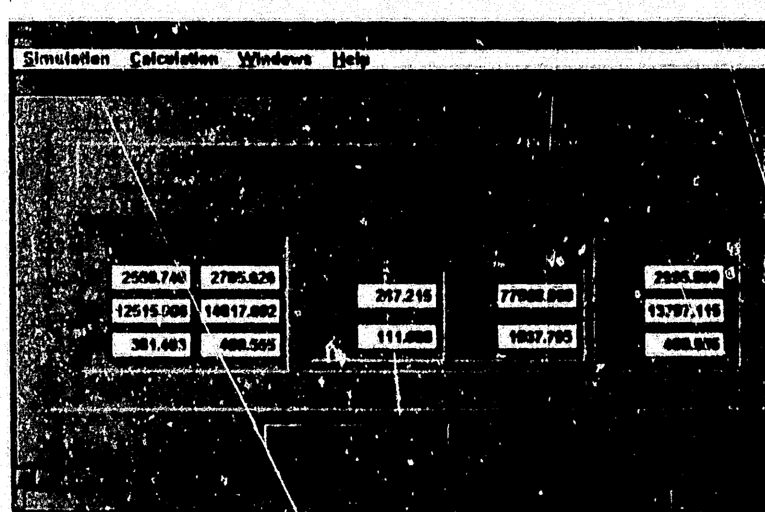

Figure 1 Substance flow output of SIMSET

As the emissions of CO_2, CH_4, NH_3 and N_2O are produced at three stages during the production process the emission of these substances were computed:

Source / Substance	Metabolism of the animal	Losses in the stable	Losses from the manure pit
CO_2	X	-	O
CH_4	X	X	X
NH_3	-	X	X
N_2O	-	X	O

X = considered, - = not considered, O = missing (due to insufficient information)

Table 2 Possible sources of emission, relevant substances and their consideration in the model

The model relates the release of pollutants to the variables of the process which the emission most significant determine. The literature review and the formulae used are described extensively in MAUL and KOCH (1996a and 1996b). A brief description of the formulae follows:

CO_2

Metabolism of the animal

x = body weight in kg,
y in g CO_2 * day^{-1}

$$y = 135.30 * 0.263^{(1/x)} * x^{0.5659} \quad \text{(MAUL and KOCH 1996)}$$

The release from the manure pit is considerable and is a function of dry mass concentration, organic matter, organic fatty acids, pH, temperature, nitrogen. However, no reliable equation was available.

CH_4

Metabolism of the animal

x = $\sum$fed MJ Metabolizable Energy (ME MJ),
y in kg released methane * pig^{-1}

$$y = (0.0069836 / 55.27) * x \quad \text{(WHITTEMORE 1993)}$$

Release from the stable

7.3 g CH_4 * $animal^{-1}$ * kg body weight $gain^{-1}$, fully slatted floor
6.6 g CH_4 * $animal^{-1}$ * kg body weight $gain^{-1}$, partly slatted floor
(both AHLGRIMM 1995)

Release from the manure pit

x = manure temperature in °C,
y in ln (g CH_4 * m^{-3} * day^{-1})

y = 1.14 + 0.17 * x, manure without crust cover
y = -2.84 + 0.31 * x, manure with crust cover (both HUSTED 1994)

NH_3

Release from the stable

0.09408 g N * d^{-1} * kg body $weight^{-1}$, fully slatted floor
0.05336 g N * d^{-1} * kg body $weight^{-1}$, partly slatted floor
(both OLDENBURG 1993)

Release from the manure pit

x1 = (g NH_4 * kg $manure^{-1}$),
x2 = manure pit surface in m^2 * temperature (°C),
x3 = manure pit surface in m^2 * air speed in (m * sec^{-1}),
y in g NH_3 * day^{-1}

y = 4.584 * x1 + 0.2127 * x2 + 1.820 * x3 - 8.203
(MAUL and KOCH 1996a)

N_2O

Release from the stable

3.1 g N * $animal^{-1}$ * kg body weight $gain^{-1}$, partly slatted floor
4.2 g N * $animal^{-1}$ * kg body weight $gain^{-1}$, fully slatted floor
(both HEINEMEYER et al. 1995)

Release from the manure pit

Losses from the manure pit are considered minimal (BURTON et al. 1993) but again no reliable formulae were available.

The user has a restricted choice of conditions for the animal environment as these conditions influence the behaviour of the manure and the emissions from the stable. Husbandry systems considered were a stable with four rows and the Danish stable system with 80 or 120 pig compartments, each of the stable systems having partly slatted or fully slatted floors, liquid or dry feeding systems and either above ground tanks or manure lake for manure storage. The restriction is due to available data about the influence on emissions of these stable systems and to sufficient supporting cost information.

Finally, a selection of direct emission reduction means can be entered such as bioscrubbers to filter stable air, different covers for the manure pit such as straw, peat, different oils, wooden or concrete covers or PVC sheets and different methods of manure acidification. Their impact on the cost of the fattening process and on the emissions retained can be examined.

For the four pollutants, CO_2, CH_4, NH_3 and N_2O, substance-specific damage cost can be entered. As a default a record is available which is derived from research of Berg (1995). These costs are calculated as local costs for ammonia and as global costs for the other substances. The local costs include damages to the vegetation caused by acid rain. The global costs are derived from models of NORDHAUS (1994). However, at present the cost estimation for the damage of pollutants is fraught with so many methodical problems that they should considered as a first step towards a quantification of global environmental goods. Therefore the data are definitely unsuitable for use in political discussions.

After the output of the substance flows (figure 1) the last menu, shown in figure 2, gives information on the cost structure per livestock unit, the total cost of the livestock and the total damage cost of emission.

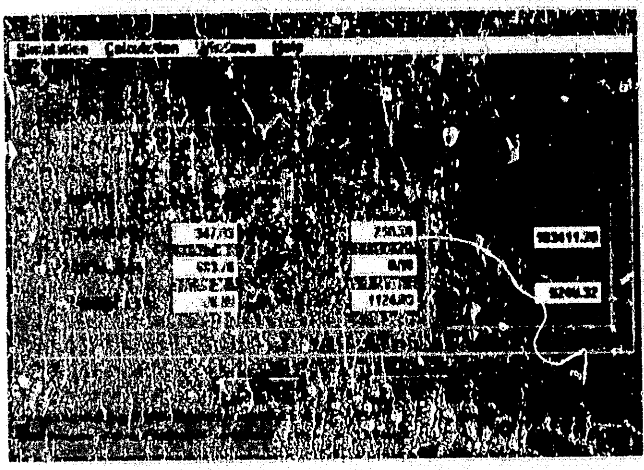

Figure 2 Cost calculation output of SIMSET

Results

Working with the model a very close relation occurred between the production intensity, the minimum or the actual substance flow and the cost per produced livestock unit. This concerned both the nitrogen and the carbon substance flows. The relation for nitrogen is shown as an example in figure 3. As the curve is calculated under ceteris paribus conditions the mathematical expression is of little interest.

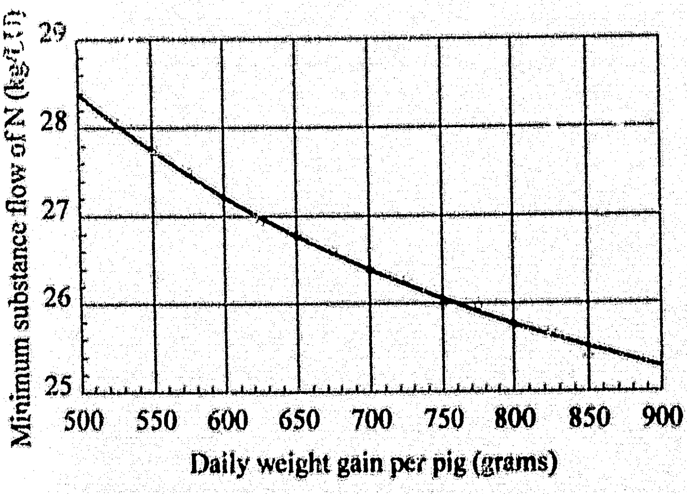

Figure 3 Minimum substance flow as function of the intensity of production

However, depending on which conditions are chosen, a linear increase in the daily weight gain is linked with a nonlinear of excreta of nitrogen. What explanations can be given for this behaviour and does this portray existing causal connections? The minimum substance flow of nitrogen is calculated as N in excreta = N in fodder - N in body substance. It assumes an ideal feed ratio which is adapted by quality and by quantity every day. Two causal connections are displayed by this behaviour of the model:

- An increase in production intensity shortens the fattening period and decreases the share of the fodder needed for maintenance
- A linear increase in the daily weight gain causes shortening of the fattening period with decreasing rates

Changing only the intensity (daily weight gain) presumes that the quality of management does not change. The Pig Report 1995 (DEERBERG et al. 1995) of the Landwirtschaftskammer (Department of Primary Industries) of the German state of Schleswig-Holstein provides sufficient data to analyse how substance flows in reality perform.

571 farms were separated into six levels of intensity, ranging from 590 to 763 grams daily weight gain per pig. The specific data for these farms like fattening period, prices for feedstuff and piglets, animal losses, fodder consumption, fodder quality were used for the model. Using these data the connection between substance flows and intensity of the process is shown in the figure below.

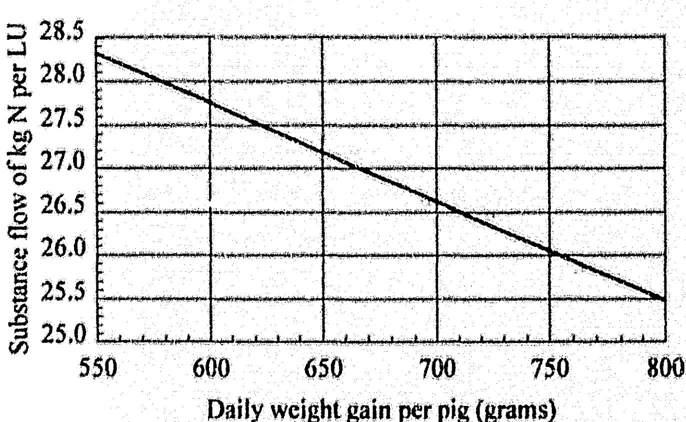

Figure 4 Calculated substance flow of nitrogen incorporating the data of "The 1995 Pig Report" DPI Schleswig-Holstein, Germany

The function is:

$$Y = 34.57 - 0.0114 * X$$

$R^2 = 0.973$

The figure shows that the curved relation has become a straight line. This indicates that the farmers in the groups with a higher intensity of production achieve their progress without a higher input but with the ability to make the input more effective. Also the differences between the calculated minimum and the actual substance flows become smaller. The table below may explain which cost structure is linked to the more efficient use of resources.

Number of fattening places/year	Average daily weight gain in grams per pig	cost of piglet (DM/LU)	cost for fodder (DM/LU)	Additio-nal varia-ble costs (DM/LU)	Cost for stable (DM/LU)	Total cost (DM/LU)
646	590	483.52	457.24	75.72	205.64	1222.12
575	636	487.78	447.47	75.28	197.32	1207.85
703	664	484.57	439.32	75.02	182.74	1181.65
563	695	493.05	427.82	74.67	181.17	1176.71
553	724	502.57	418.22	75.09	174.22	1170.10
463	763	503.03	401.93	74.64	174.17	1153.77

Table 2 Size, intensity and cost structure per livestock unit in the pig industry

The most intensively producing piggeries spend slightly more money for piglets and have about 5 % lower total costs than the less intensively producing group. Two thirds of the cost savings originate from the fodder costs and one third from the cost of the husbandry system. The fodder costs per ton oscillate in a range of 1 %, so higher quality is not caused by more expensive components but by a better feeding regime and/or an appropriate composition. The cost calculation of the DPI in Schleswig-Holstein is carried out as a gross margin calculation, so the costs for the stables are not available and are derived as average costs from the model. The fewer livestock in the high yielding groups create more expenses for a pig place per year but the shorter keeping period compensates this influence.

In fact there are many factors which may influence the substance flow and subsequently the economics. These are: hygiene, animal health, constitution of the animals, climatisation of the stable, differences between breeds, feed quality or regime or general management practices like all-in all-out practices. If they are not at an optimum any of the factors will cause a "waste" substance flow or, if there is no reserve, a depression in weight gain. Apart from difficulties in measuring the substance flows exactly, the analysis of substance flows seems to be an accurate instrument for assessing the level of management and the efficiency of the production technique. SIMSET is not a tool for analysing production problems but it is certainly a tool which can be used to detect problems.

How do the expected emissions for the different classes of farms develop? To assess the substances they have to be made comparable. The record of damage cost used(BERG 1995) is shown in the table below.

Estimated damage cost of aerial pollutants (DM per kg)			
CO_2	CH_4	NH_3	N_2O
0.03	0.60	4.10	8.00

Table 3 Cost of aerial pollutants

Using this record of damage costs the pollutants showed a significant decrease with an increase in the intensity of production (see table No 4). This decrease is also a consequence of the shorter fattening period. The release of CO_2 is a function of body mass and time, CH_4 is a function of the fodder intake, the weight gain, the floor conditions, the days of storage, temperature and a natural or artificial cover of the manure pit, NH_3 is a function of the floor conditions, manure pit surface, manure temperature, air velocity and the days of storage and N_2O is a function of the weight gain and the floor conditions. Some of these variables are influenced by a higher intensity of the production process, others are not. However, because the release is quite frequently a function of time, the emission situation seems, in principle favourable for a higher level of intensity.

Classes of production intensity: grams weight gain per day	590	636	664	695	724	763
Damage cost (DM/LU)	61.68	58.10	56.71	54.41	52.49	50.21

Table 4 Decrease in environmental damage cost determined by production intensity

Emission reduction means intervene at a certain step of the production either the process of keeping the animals or their metabolism or the storage of the manure. They generally do not cover the entire process. They often use distinct physical or chemical characteristics which apply to one pollutant but not to the other. The efficiency of some emission reduction means ranges from 50 % up to 95 % concerning one pollutant and may be zero for another. For CO_2 there are no useful emission reduction means at all except photos[illegible]sis and that is not able to be integrated in the pig production process. However, given the record of table 3 and given the fact that there are still some details of the model missing (see table 1) the table below shows how emission reduction means perform under a holistic view of emission.

Emission reduction means	Daily weight gain in grams per pig	Cost for emissi. reduction means	Damage cost for pollutants	Total cost
None	590	0.00	61.68	1222.12
	675	0.00	55.80	1167.83
	763	0.00	50.21	1153.77

Wooden or conctrete cover of the manure pit	590	4.65	51.47	1226.77
	675	3.57	46.90	1171.90
	763	3.57	42.47	1157.34
PVC-sheet to cover the manure pit	590	3.17	51.78	1225.29
	675	2.77	47.17	1170.60
	763	2.43	42.71	1156.20
Straw or peat cover of the manure pit	590	0.49	52.42	1222.61
	675	0.43	47.57	1168.26
	763	0.37	43.06	1154.14
Cover of the manure pit with mineral oil	590	1.82	51.32	1123.94
	675	1.59	46.77	1169.42
	763	1.39	42.36	1155.16
Cover of the manure pit with plant oil (rape seed)	590	6.36	51.78	1228.48
	675	5.58	47.17	1173.41
	763	4.88	42.71	1158.65
Biofilter for the air of the stable	590	32.56	56.76	1254.68
	675	28.60	51.40	1196.43
	763	24.99	46.32	1178.76
Acidification of the manure with nitric acid	590	49.33	50.05	1271.45
	675	48.90	45.58	1216.73
	763	48.62	41.10	1202.39
Acidification of the manure with lactic acid	590	394.60	49.40	1616.72
	675	391.18	44.90	1559.01
	763	388.98	40.60	1542.75

Table 5 Effect and cost of different emission reduction means in conjunction with different intensity levels on damage costs, costs and total costs (DM per LU)

As the table above shows is the contribution of the emission reduction means nearly constantly DM 10.00 independent from the sometimes considerable cost differences which also can be achieved with a more intensive production.

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